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VERTICAL SAND DRAINS FOR STABILIZATION OF MUCK-PEAT SOILS

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HIGHWAY DIVISION

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VERTICAL SAND DRAINS FOR STABILIZATION OF MUCK-PEAT SOILS

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INTRODUCTION

When we speak of drainage, we visualize a fluid pulled down hill out of a saturated mass which will become a better material if the fluid is removed. Gravity pulls the moisture out of the mass. In this discussion we will reverse the direction of flow and push the water upward. Gravity will do the work, by pulling down on a superimposed load and squeezing the moisture out of saturated soils. An avenue of escape for the moisture will be provided by installing vertical sand drains, and a horizontal sand layer to conduct the water to the side of the embankment.

The California State Highway Department pioneered and developed this method of treatment of marsh soils. Mr. O. J. Porter, Associate Physical Testing Engineer, presented a comprehensive discussion of the subject in his paper published in Highway Research Board Proceedings of 1938.

STABILIZATION WITH VERTICAL SAND DRAINS IN PUERTO RICO

Outside of California, this method of stabilization of soils to provide support for embankments had not been widely used prior to 1941. At that time Puerto Rico was pushing the construction of its vitally important link in the strategic military network on north coast highway number 2 from San Juan, eighty miles to Borinquen Field (now Ramey Field). This route as it leaves San Juan crosses a marshy area between Fernandez Juncos Avenue and the Martin Peña Channel known as "El Fanguito"' which means "Little Mud." The "little mud" extended 0.34 mile along this location. The mud was 25 to 50 feet deep, covered with water at high tide and so soft that at low tide barefoot boys sank ankle deep. Projection of a four-lane highway across this quaking custard-like foundation presented a serious problem. The Puerto Rico Department of the Interior studied numerous schemes and prepared estimates of c nstruction costs. Seven ideas seemed to be practicable. These ranged from a timber trestle at $187,000 through excavating the muck and refilling with good material at $390,000 to a concrete trestle at $600,000. Mr. A. C. Clark, then District Engineer for the Public Roads Administration in Puerto Rico, reviewed the project and suggested that the vertical sand drain method as used in California be included as an alternate. Plans were prepared and the cost by this method was estimated at $103,200. Late in 1941 the project was advertised for bids, but due to some apprehension as to the success of the method, the advertisement was withdrawn before bids were received.

The plans were reviewed by Mr. Carpenter early in 1942 and, after some very helpful correspondence with Mr. Porter, they were revised to fit local conditions. One important change was the diameter of the drains. The

original plan proposed 30 inch sand columns to be placed by drilling a well with an auger or by driving a mandrel. In this supersaturated muck it is impracticable to drill with an auger and there was neither equipment nor material available on the Island for a mandrel of this size. The twelve-inch steel pipe was available so the plans were changed to decrease the spacing of the drains and use the 12-inch size.

The project was of importance in the war effort. The Navy had equipment and materials which could not, at that time, be furnished by civilian contractors. On appeal to Captain J. C. Gebhard, Public Works Officer of the San Juan Naval Air Station, he agreed to build the project if it were approved by the Bureau of Yards and Docks. The project was converted to access project number DA-WR1 and promptly approved for construction. Work starte in November 1942. Commander J. G. Dodd, Member A.S.C.E., was in charge of the Navy contract work during their participation.

At this stage another important change in plans was approved. The contractors for the Navy could not support their equipment on the surface of the marsh. It was agreed that a tough clay blanket not thicker than two feet would be placed. It was understood that the sand columns must extend well above the top of this blanket so that no clay stratum would cut off the vertical drainage action (Figure 1).

The field superintendent for the Navy misunderstood instructions about the clay blanket and started placing a fill of rock quarry waste. After about two hundred feet of the right-of-way had been covered a mud roll developed on the side of the embankment, the transmission tower began to move and a 36" sewer was shoved out of line (Figure 2).

Filling was immediately suspended and on its resumption the clay layer was successfully placed over the entire area.

The mandrel used was a 40-foot section of 12" steel pipe. To close the lower end of this pipe concrete conical points 14" in diameter with a 12" cylinder on top to fit the inside of the mandrel were cast. The mandrel was driven with a steam hammer in 50' leads. Drains were spaced 11.8 feet transversely and 9.8 feet longitudinally. The area covered was 90 feet wide for the length of 0.34 mile. In all, 1,492 drains totalling 57,685 lineal feet were placed at an average cost of $0.93 per foot. A wooden punch was driven through the clay blanket, the mandrel, with its concrete point, was placed in the hole and driven 40 feet, or to refusal. The mandrel was filled with saturated sand which was heaped above the top of the driven mandrel and the mandrel then withdrawn leaving the concrete point and the column of sand in the muck (Figure 3).

The California method provided for a two-foot blanket of sand on top of the drains to carry the water to the sides of the fill. We anticipated a settlement of fifteen to twenty feet below mean low water and believed there might be danger of slides if a heavy clay fill were placed on a two-foot sand blanket. Sand from the harbor bottom could be obtained at a reasonable cost so it was decided that a sand fill would be placed for the full depth below the marsh surface and above the clay blanket.

The Navy placed 44,000 cubic yards of sand fill between February and July 1943. The fill was four feet above the marsh level. Due to administrative changes in Navy operations, the work was suspended on July 13, 1943. The project was taken over by the Insular Department of the Interior on May 21, 1944. Recognizing the necessity for slow and careful application of the remaining sand fill the Department awarded three small contracts extending over the period from May 1944 to July 1945 and a final contract terminating the fill construction during December 1945. Insular Department contracts

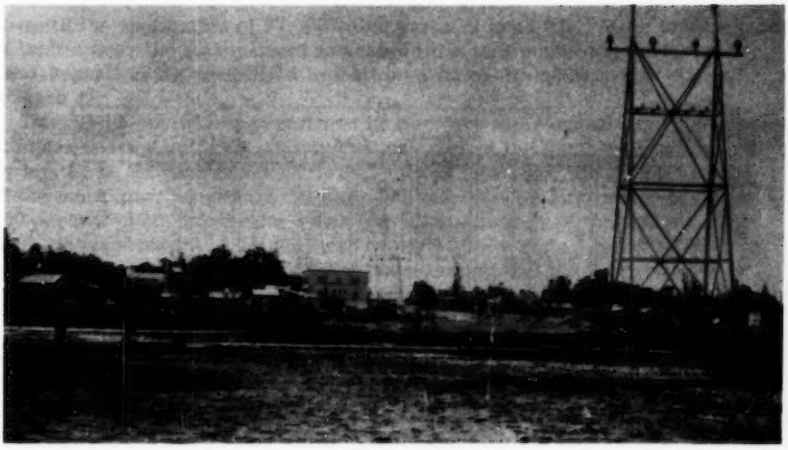

Figure 1. "El Fanguito," Puerto Rico, marsh at low tide. Transmission tower and air raid shelters.

Figure 2. Heavy fill placed at the beginning of operations caused a mud roll, pushed a 36" sewer out of line and moved the transmission tower.

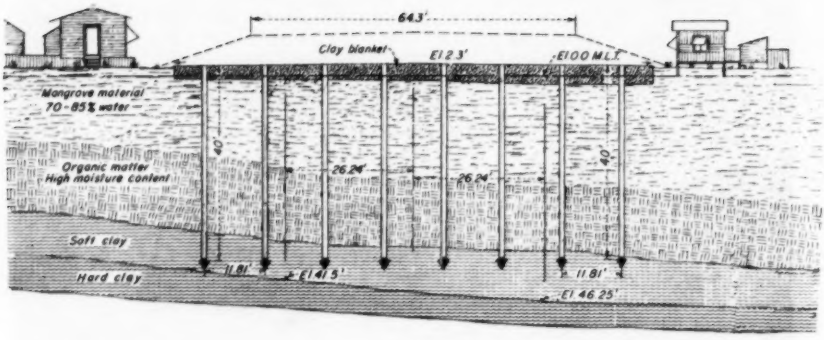

Figure 3. Typical Cross-section through "El Fanguito" marsh showing clay blanket and vertical sand drains with concrete points before the embankment load had been applied.

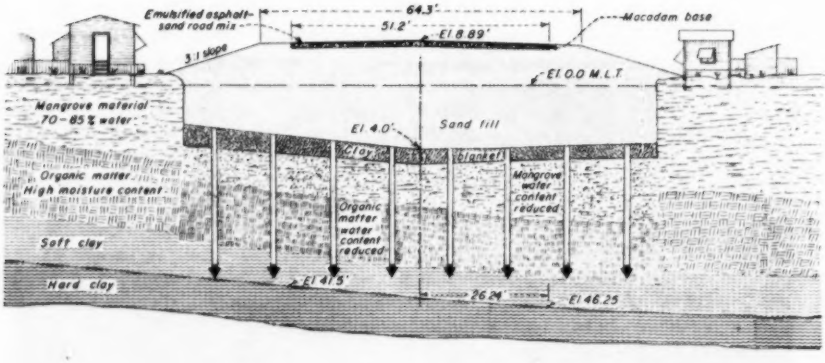

Figure 4. Typical cross-section through the "El Fanguito" marsh showing the penetration of the clay blanket and the sand fill in the muck. The center elevation of the clay blanket is 4.0 meters, approximately 14 feet below mean low tide. The cross-section was developed from soundings made through the sand fill, clay blanket, muck soil and into the clay by Mr. Antonsanti of Ponce.

covered the application of 77,000 cubic yards of sand fill. After three months of traffic over the embankment indicated little settlement the surfacing of sand-asphalt using emulsified asphalt on a water-bound base was applied (Figure 4).

During the operations performed by the Navy their consulting Engineers, Madigan and Hyland, took undisturbed samples of the muck which were tested by Mr. E. K. Tan at Roosevelt Roads. It was found that the moisture content of the muck-peat ranged from 140 to 700 percent with an average of about 400 percent of its dry weight which was approximately 20 pounds per cubic foot. Shear strength of the soil was negligible, the material failing of its own weight when unconfined. Model tests showed that the muck would consolidate twice as fast with vertical sand drains as without them. Mr. Tan predicted that the depth of sand fill to provide stability would be between 10 and 19 feet. His predictions were very close to the actual depth placed.

In May 1943, during the Navy operations, a slip occurred on a section about 200 feet long at the center line of the fill near the Martin Peña end of the project. The fill dropped a foot in the east-bound lane and there was some movement in the other lane. Filling was stopped for a week at this point and then very slowly resumed. No additional faulting occurred during the construction period, but this area has given trouble under traffic. (Figure 5).

The rate of settlement was measured by observations on upright posts placed on settlement platforms installed at the top of the clay blanket at 50 foot intervals along the center line. Unfortunately, during the period when the work was suspended the vertical posts were all carried away and it was not possible to reinstate them without considerable expense. However, the settlement of the top of the fill after heavy rolling provided a reasonably satisfactory record of comparative time-settlement. This record was supplemented by borings made by Mr. Antonsanti.

An attempt was made to measure the pore-pressure in the muck-peat soil. Six cylinders with standpipes attached were placed at varying depths at uniform intervals along the center line. Only one of these pressure cells showed any indication of high pressure. This one was near the site of the fault on the center line. On the day before the slip occurred the water ran over the top of the standpipe about four feet above the elevation of the grade at that point.

In carrying out this stabilization there was considerable risk involved. Previous use of this method had not involved soils with such a high moisture content. We had very meagre information on the character of the soil to be treated and the volume of water to be removed could not be accurately calculated. Size and spacing of drains were arbitrarily determined and through good fortune this determination seemed to be adequate. The embankment has served satisfactorily except at one point over a period of six years. On Cerra Street, paralleling this project along the harbor front, borings made through the surfacing showed that as much as eight feet of macadam has been placed at several points.

The success of this project may be attributed to the slow rate of construction, to the use of a tough clay plate under the sand fill and to the use of sand in the embankment above the clay blanket.

COMMENTS ON EMBANKMENT CONSTRUCTION ON SOFT SUBSOIL

When a highway embankment is constructed it tends to spread laterally and to consolidate its foundation. If the foundation is firm, the consolidation is small and it develops strength enough to support the fill. However, on a

soft soil the lateral stresses from the fill displace the foundation. Several methods of treatment have been developed and are successfully used. Four methods are briefly described.

(1) Displacement of soft soil and replacement with acceptable embankment material.

Pre-excavation of the soft material and backfilling provides the best foundation, but is only economical for shallow depths (10 ft. or less). For greater depths blasting or jetting have been used to displace soft materials from under the center of the fill to obtain support from the firm material below and eliminate long-time settlement due to consolidation. Granular fill is used so that it can adjust its shape without cracking as the soft material is displaced. Large stones are not suitable because soft soil will destroy their aggregate stability by intrusion unless they are placed on a special blanket. Displacement is often difficult to control, especially for depths over 10 to 20 feet. Much less fill will be required if all the foundation material could be kept under the fill.

(2) Floating embankment on soft soil.

When the foundation is almost strong enough, a stable condition may be obtained by reducing the overturning moment either by a reduced load from less height or lighter material, or by addition of a balancing load. Where a meadow mat or constructed willow mattress controls the lateral stresses the fill can often be floated on a soft foundation although settlement due to consolidation must be anticipated. As the soil consolidates, it becomes stronger so that, if the fill were constructed slowly enough, moderately high fills can be built on initially very weak soils. The section of Puerto Rico Highway No. 2 between the Martin Peña Channel and Fort Buchanan was built on a natural mat of mangrove roots.

(3) Drainage

Time required for natural drainage of deep deposits, if it is practicable, is usually prohibitive unless special drainage is provided. Vertical sand drains reduce the time for consolidation by shortening the distance the water squeezed from the soil must travel and by taking advantage of horizontal seams of more permeable material which are often present in soft foundations. Thin seams of weak clay sometimes occur in the subsoil of generally strong material under an embankment. The weight may cause the material above this weak clay to slide out laterally and let the fill down. Slow construction usually will provide adequate consolidation of thin clay seams in relatively permeable soil or of thin surface layers of clay if permeable material is used in the base of the fill.

(4) Bridge Foundations

Control of settlement and lateral thrust are especially important where utilities or structures are adjacent to the fill as for fills approaching bridge abutments. If the soft layer is thin, replacement of the soft layer with granular fill may be possible. However, for deep soft strata, drainage with vertical sand drains may be indicated. A surcharge above the fill may be

used to accelerate the final consolidation and prestress the soil for the bridge load. When the required consolidation is realized the extra fill may be used to flatten slopes. In volcanic or soils having a large percentage of organic material secondary consolidation which is not accelerated by drainage may cause some continued settlement.

DESIGN FEATURES FOR VERTICAL SAND DRAINS

The sand-drainage system consists essentially of a sand blanket 2 to 3 feet thick connected to vertical columns of sand 12 to 30 inches in diameter. The theory of vertical sand drains is that the channels filled with sand will allow the pressure of the fill to squeeze the moisture out of the muck, peat, soft clay or other soil. The moisture will then be forced up through the sand drains to the sand blanket and laterally through the blanket to the edges of the fill (Figure 6). The sand blanket is extended beyond sides of the fill so that drainage will not be blocked as the fill settles and forces the water up and out. In special cases, drainage may be directed downward into unsaturated material. Pumping from the drains may produce some consolidation by gravity drainage but the force available is limited. For ideal conditions the required spacing of drains for a given construction schedule can be calculated from shear and consolidation test results on undisturbed samples.(1) A center to center spacing of 10 feet is common but 15 feet has been used where time for consolidation was not at a premium. Five feet spacing has been used at bridge abutments where immediate construction was required. A square array is often used although a hexagonal array is more efficient. In Sweden cardboard wicks have been used in clay with 2-3 feet spacing.

The sand for the drains and blanket should have a coefficient of permeability of at least 15 feet per day and yet be fine enough to prevent intrusion of the surrounding soil. A typical grading specification used on the New Jersey Turnpike is:

Sieve	Percent Passing
2-1/2 inch	100
1/2 inch	60-100

Of the material passing the No. 4 sieve, not more than 20 percent shall pass the No. 80 sieve and not more than 2 percent pass the 200 sieve.

For very wide fills permeability of the blanket may be augmented by the incorporation of drain pipes or gravel windrows.

CONSTRUCTION OF VERTICAL SAND DRAINS

If the natural surface will not support construction equipment, a working platform is required. This may be a clay blanket for very soft soil such as found in "El Fanguito," mats, ordinary fill, or an extra thick sand blanket. If the sand blanket is too loose, the equipment may work on about 3 feet of fill above the blanket.

The drains may be installed by any method that leaves clean sand in a continuous column from a firm base to the sand blanket. A much used method involves the use of a mandrel or closed end pipe driven or jetted down where necessary to penetrate hard layers. (For hard driving, smaller pipes have been driven or double-walled pipes used for jetting). Jets should not be used

Figure 5. Pavement depression on the center line of "El Fanguito" project where a slip occurred during construction.

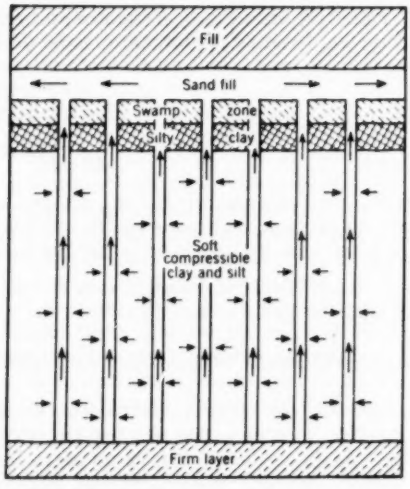

Figure 6. New Jersey Turnpike. Illustrating the theory of stabilization with vertical sand drains.

in the soft soil since they tend to smear over permeable layers and contaminate the sand with muddy water. The pipe is filled with sand by a skip hoist as it is being driven. (Figure 7). When the required depth is reached compressed air (or steam) is applied above the sand to prevent its rising as the pipe is pulled and to aid in pulling. If the blanket was not previously placed, a mound of sand is left above the hole to insure continuity with the blanket.

The fill must be placed uniformly in thin layers. Specifications include a limit to the rate of loading and provision for added delay if field observations indicate danger of overstressing the foundation.

CONTROL

Borings and tests of the subsoil are required for design before construction. Limitations on exploration, especially the uncertainty of extent and drainage of more permeable strata or lenses, make it advisable to check the progress of consolidation during construction. These checks may indicate the necessity of slower loading to prevent overstress or possibly show that more rapid construction is permissible. Complete records also assist in improving designs for future projects.

Settlement plates placed on the subgrade or on the blanket permit measurement of the settlement of the embankment. Settlement plotted against time indicate the stage of consolidation reached. Settlement records are also used for determining contract fill quantities (Figure 8).

Displacement stakes in rows beyond the toe of fill indicate, by outward movement, overstress leading to lateral sliding (Figure 9).

Well points or waterpipe, perforated at the lower end, are placed in holes drilled between the drains, surrounded by sand and the hole sealed. After filling the pipe with water, a pressure gage attached to the top measures pore pressure. Since the pressure effective in developing the strength of the soil is the total pressure minus the pore pressure, an excessive pore pressure means insufficient effective pressure and therefore insufficient strength. The allowable pore pressure depends on the geometry of design and the soil characteristics but must generally be kept below 50 percent of the total pressure. In several cases where controls were inadequate, slides have occurred which destroyed the drains and necessitated reconstruction (Figure 10).

On some projects the pore-pressure is measured in vertical pipes extending up from well points or pressure cells. On the California project built in 1933-34,[2] standpipes were installed to provide measurement of hydrodynamic excess pressure. A project in the Los Angeles area on the Terminal Island Freeway,[3] built in 1947 used a pore-pressure apparatus involving a 10" x 2" well point at the bottom of a 3/4" pipe driven to the depth where the pressure is desired. The riser pipe is connected through two 3/4" tubes to a gauge and air cock on a post outside of the fill area. Comparative readings of the gauge indicate the variation in pore-pressure. On a Maine Project now under construction, the pore-pressure readings are obtained through an apparatus consisting of a pressure cell set at an elevation in the muck soil where pressures were desired. This cell was placed by driving a four-inch pipe, cleaning out and setting the cell, then filling above the cell with sand, partially pulling the pipe and sealing the top of the sand. From the cell, transparent plastic tubes extend upward above the fill (Figure 11).

It is customary to place an overload on the embankment area by filling

Figure 7. New Jersey Turnpike. A typical sand drain rig used to place drains through deep mud formations of the Jersey Meadows section. With loads as high as 115 feet, mandrels up to 90 feet were driven. Each hole is filled with sand loaded into the side of the mandrel from the skip as shown on the slide.

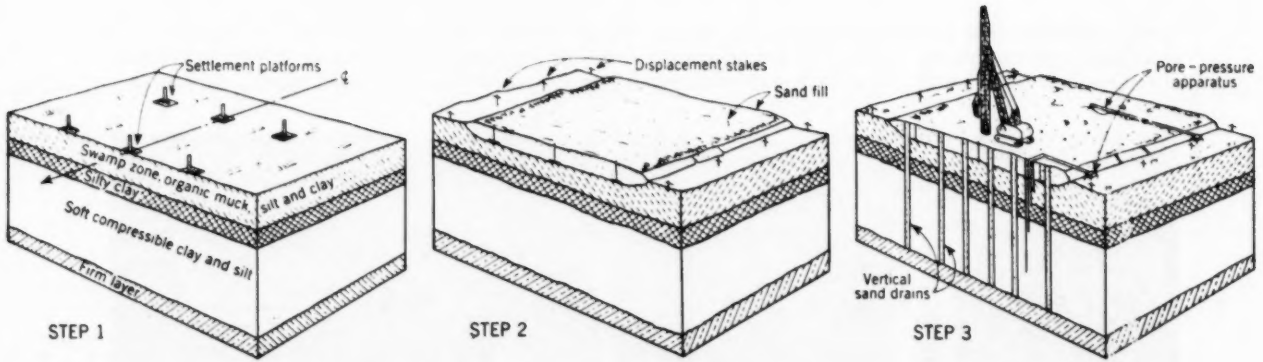

Figure 8. N. J. Turnpike. Step No. 1. Settlement platforms were placed on the original meadow surface. Platforms were either timber or steel rectangles approximately 3 feet by 3 feet. In the center of each platform a vertical pipe was attached to extend upward through the fill. Extensions to this pipe were added as the fill is built up.

Figure 9. N. J. Turnpike. Step No. 2. Porous sand fill was placed on the meadow surface and displacement stakes set outside the fill. The sand blanket was placed 3 or more feet in depth. Because the sand lacked fines to provide a satisfactory working surface for heavy equipment, contractors were allowed to deposit gravelly material containing not more than 15% fines on top of the sand blanket to form a working table.

Figure 10. N. J. Turnpike. Step No. 3. Vertical sand drains were installed through the clay, silt, peat or muck subsoil materials. Some of the drains were 100 feet deep. Pore-pressure measuring devices were set at various depths. The mandrels used on this project were 14 to 20 inches in diameter. Air pressure pushed the sand out of the bottom of the mandrel as it was withdrawn. The pore-pressure gauges were read periodically and control of the rate of loading the embankment was based on the differential readings. Over 100,000 pore-pressure readings were made on the New Jersey Turnpike.

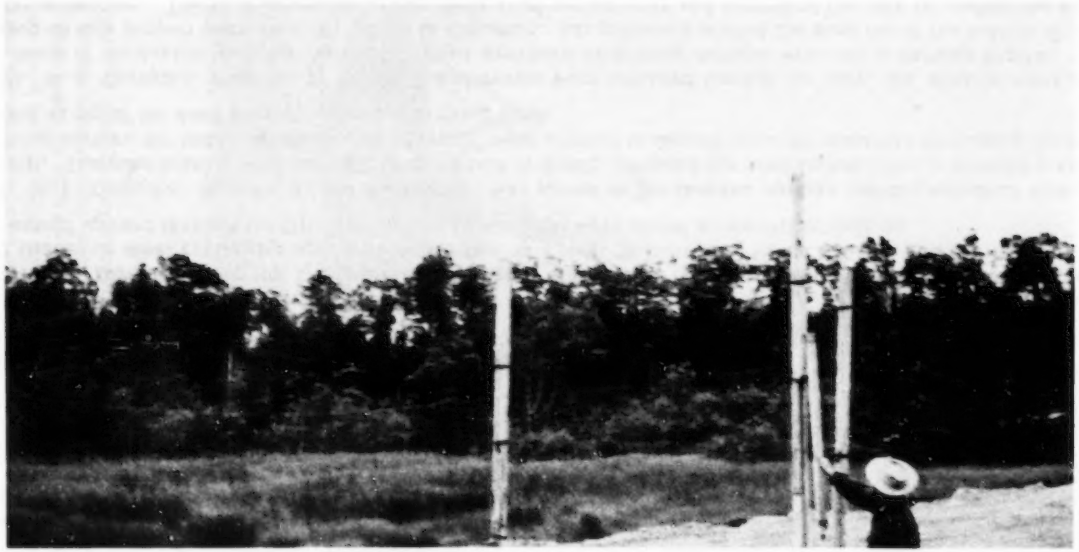

Figure 11. Maine Secondary Project near Bath. Pore-pressure apparatus. Three pressure cells were placed at elevations 14 feet, 24 feet and 44 feet below the surface of the marsh. Elevations of the water in the transparent plastic tubes were recorded each day and the placing of embankment was suspended when the elevations indicated unsafe pore-pressure.

above grade. After the sand drains have been placed fill material is gradually placed and compacted in thin layers. The pore-pressure gauges, settlement platforms and side displacement stakes are watched. When any unusual movement is observed the filling is stopped until conditions reach a state of equilibrium. After the fill reaches profile grade, 2 to 8 feet of overload is placed and allowed to stay in place for at least three weeks before it is plowed off to the sides of the fill (Figure 12).

When the time-settlement curves show a definite tendency to flatten out, it is known that the stabilization is nearing completion and the overload may be safely removed (Figure 13).

The removal of the overload sometimes results in a slight rise in the embankment which may require two to four weeks time for adjustment before paving is placed (Figure 14).

EXAMPLES OF THE USE OF VERTICAL SAND DRAINS

The Highway Research Board Department of Soils Investigation, Mr. Harold Allen, Chairman, recognizing the necessity for research in the treatment of subsoils for support of highway embankments, organized Project Committee No. 13 "A Survey and Treatment of Marsh Deposits" with Olaf L. Stokstad, Engineer of Soils, Testing and Research Division, Michigan State Highway Department as Chairman. The use of vertical sand drains is particularly applicable to the treatment of marsh deposits and Committee No. 13 is engaged in the accumulation of information on this process. There are several phases of the committee work which may be classified as research. The accumulation of all available important information on the treatment of marsh deposits, correlation of this information and publication in a bibliography with brief abstracts of the texts, is now under way. Research is needed on the classification of the soils in marsh deposits so that the most economical method of treatment may be rather definitely prescribed. The committee has this phase under study and expects to develop procedures as the study is continued. In the field of vertical sand drains there is need for the issuance of more comprehensive information on the types of soils to which this method is applicable and the preliminary tests that must be made to be sure the design is economically correct in the choice of method. The size and spacing of drains, thickness of sand blanket and other design features are dependent upon the character and extent of the material to be treated. The theory of design has been covered by soil scientists, as in Mr. Barber's discussion.(1) The application of this theory requires a comprehensive knowledge of the character of the marsh deposits. In the construction phase, there is need for research on the use of pore-pressure devices to determine the best type to be used, to collect and publish information on the analysis of the readings obtained and the application of the results of these analysis to the control of the embankment construction. Other research phases may develop as the committee proceeds with its operation.

Outstanding projects constructed using vertical sand drains are here listed and briefly described. In 1934 the easterly fill approach to the San Francisco-Oakland Bay Bridge was the site of a standpipe test to measure the nature and intensity of pressure developed by the application of a load to a saturated material. Vertical sand drains were not used on this project but the information obtained from this experiment was used in the development of the California practice. The first application of vertical sand drains was on a portion of the Redwood Highway near Eureka across Beatriz Marsh.

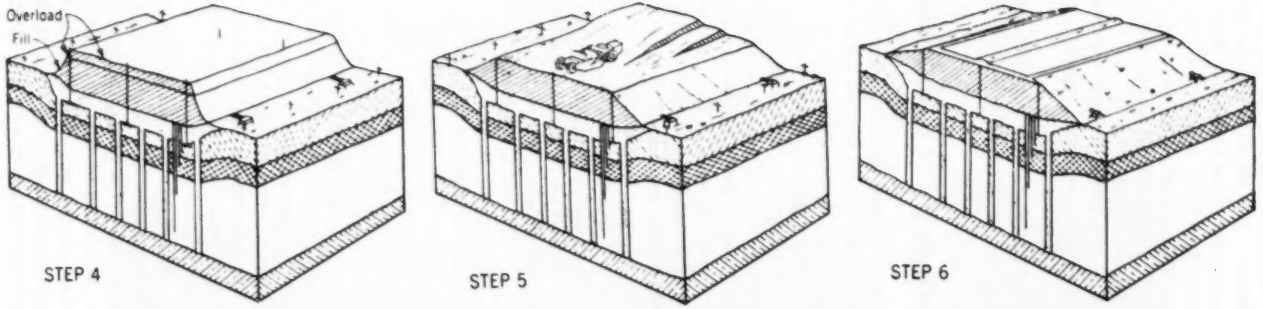

Figure 12. N. J. Turnpike. Step No. 4. Overload material was placed in controlled increments, depending on gain in strength of marsh material as determined by readings of field instruments, and soil laboratory tests.

Figure 13. N. J. Turnpike. Step No. 5. After consolidation the over-load fill was removed to widen the embankment and flatten the slopes.

Figure 14. N. J. Turnpike. Step No. 6. The final stabilized roadway with the surfacing in place. Pore-pressure devices and settlement platforms were left in place for future observation.

Here 84 drains, 28 inches in diameter averaging 42 feet deep, and aggregating 3530 lineal feet, spaced 10 and 20 feet apart, were installed. Stabilization with vertical sand drains was successfully used on the East Bayshore Highway Approach to the San Francisco-Oakland Bay Bridge in 1936 and the Cuesta Grade Project in 1937.(2)

After the results of the test at the Beatriz marsh became available, the California Highway Department embarked on a program of application of this method to the stabilization of soft subsoils and in fourteen years the foundations on 22 projects, aggregating 1,108,807 lineal feet of drains, had been treated.(4)

The use of vertical sand drains in the eastern part of the United States did not develop until the end of World War II. Connecticut constructed a project at the Old Lyme Bridge(5) and has since developed a project on the new location of the highway crossing New Haven Harbor.

New Jersey used vertical sand drains for stabilization of muck under their route 100 and on other marsh projects.(6)

The use of vertical sand drains on "El Fanguito" project is described in an article in Engineering News-Record July 22, 1948.

The largest project using this method of stabilization is the New Jersey Turnpike. Five million lineal feet, approximately one thousand miles, of sand drains, ranging in depth from 12 to 100 feet, were used on this project.(7)

Vertical sand drains have been used for treatment of areas used for types of construction other than highway. As examples, the LaGuardia, New York Airport(8), Pier 57 in the Hudson River, New York City(9) and railway embankment construction (10) (Figure 15).

Federal aid projects are under construction using vertical sand drains in California, New Jersey, Rhode Island, Connecticut, Washington, Hawaii and Puerto Rico.

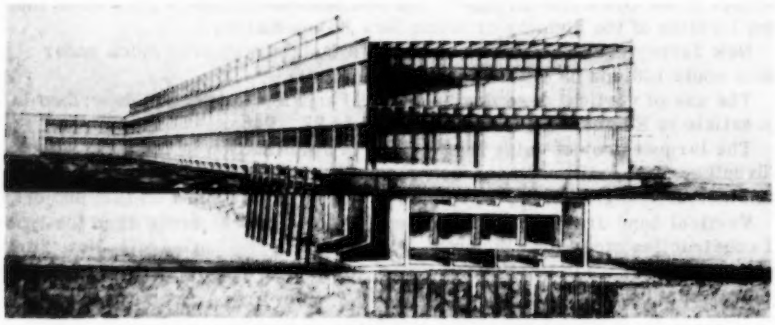

Figure 15. Pier No. 57 being constructed by the Department of Marine and Aviation, New York City will rest on vertical sand piles and a sand mat. From "Civil Engineering" March 1952, page 37.

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10. Sand Drains Reversed by Well-point System, by Byron J. Prugh, Engineering News Record, June 5, 1952.